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13. ABSTRACT


Relationships between human response and digital television encoder parameters were investigated by measuring subjects' minimum perceptible acuities. Variations in sampling frequency and quantizing noise were simulated for a differential pulse code modulation encoding system by changing bandwidths and signal-to-noise ratios of pictures displayed on the monitor of a closed circuit television system. Noise had little or no effect on the minimum perceptible acuity over the ranges tested. Information transmission was profoundly affected by bandwidth and very little affected by noise in the system. This was true for all degrees of system complexity and cost tested.




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# OPTIMIZING INFORMATION TRANSMISSION IN A DIGITAL TELEVISION ENCODING SYSTEM

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Relationships between human response and digital television encoder parameters were investigated by measuring subjects' minimum perceptible acuities. Variations in sampling frequency and quantizing noise were simulated for a differential pulse code modulation encoding system by changing bandwidths and signal-to-noise ratios of pictures displayed on the monitor of a closed circuit television system. Noise had little or no effect on the minimum perceptible acuity over the ranges tested. Information transmission was profoundly affected by bandwidth and very little affected by noise in the system. This was true for all degrees of system complexity and cost tested.

## INTRODUCTION

A television signal is always an imperfect reproduction of an image. Various factors inherent in the development and transmission of a signal act to impair or degrade the quality of the received image. Such image impairments degrade both observer performance in target detection and monitoring tasks (Humes and Bauerschmidt, 1968) and observer enjoyment of entertainment programs (Dean, 1960).

Most new transmission systems for speech or television employ some form of digital encoding. Signals are segmented at some periodic frequency into discrete samples of the original waveform. This sample is then translated

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into a binary code, and the code becomes the transmitted signal. A decoder reconstructs the signal into its original analog form at the receiver.

The most promising digital encoding system now being investigated is Differential Pulse Code Modulation (DPCM). Instead of encoding each signal sample according to its amplitude, as is done in traditional encoding systems, a code is generated according to the difference in amplitude between the present sample and a predicted value based on the previously transmitted signal.

By only transmitting the encoded difference, signal redundancy may be removed, and this improves the efficiency of information transmission. DPCM uses this redundancy to make highly accurate predictions of sample amplitude. Hence, fewer binary codes may be transmitted to achieve the same resultant analog signal.

However, the effectiveness of the DPCM system is determined by the sampling frequency of the encoder and by the number of amplitude levels being encoded. The sampling frequency of a television encoding system determines the horizontal resolution, and therefore the bandwidth of the displayed signal. The number of encoding levels determines sample amplitude sensitivity, and thus affects the signal-to-noise ratio of the television picture. This noise resulting from the DPCM encoding process is called quantizing noise and appears as "snow" in the image. Increasing sample frequency and/or levels per sample raises the system bauderate -- the number of binary symbols encoded per second. Such an increase affects the television picture as increased bandwidth and improved signal-to-noise (S/N) ratio.

The cost of a digital transmission system is directly related to its bauderate. Theoretical equations have been presented to describe curves of

constant cost and associated bauderate relative to given signal bandwidths and S/N ratios (O'Neal, 1967). Binary symbol transmission rate and equipment cost are relatively constant along such curves. Referring to Figure 1*, system cost and symbol transmission rate are exactly the same at 1.0 MHz bandwidth and 44.5 db S/N as they are for 2.5 MHz bandwidth and 31 db S/N.

Although bauderate may be increased, the relationships between the human's response to pictures generated by varying sample frequencies and/or levels per sample on a constant curve are not known. The purpose of the present study was to measure the minimum perceptible acuities of subjects under various noise-bandwidth conditions, and to relate these acuities to system costs according to the constant cost/bauderate curves.

## METHOD

### Subjects

Twelve North Carolina State University students taking an introductory psychology course served as subjects in the experiment. All subjects had 20/20 corrected visual acuity.

### Apparatus

A high quality closed circuit television system was used to determine the relationships between human perception and encoder parameters. A Fairchild Model TC-177 RL vidicon camera generated the wideband NTSC standard (525 line entertainment TV) black and white video signals.

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*This figure was plotted from Equation (11) in (O'Neal and Agrawal, 1970).

Variations in sample frequency and levels per sample were simulated by changing bandwidths and signal-to-noise ratios of the pictures. Wideband random noise was obtained from a General Radio Model 1383 Random Noise Generator. The noise level was controlled by a Hewlett Packard Model 3750A attenuator, which could be adjusted in one decibel (db) steps from 0 to 99 db attenuation. Video signal bandwidth was controlled by a Khron-Hite Model 3103R filter. Slight circuit modifications were made to allow continuous frequency adjustment from .5 to 3.0 MHz with a 24 db per octave attenuation curve. A Conrac Model RND-9 television monitor with a useful bandwidth of 10 MHz was used to display the images.

The camera's video signal was sent to a signal mixer, where the signal and random noise were combined. This resultant signal was then sent to the filter and on to a timed switch, where presentation time of the signal was controlled. Between presentations of test stimuli, subjects only saw a raster (continuous field of illumination) on the monitor. By pressing a pushbutton to start the electronic timer, the test image was presented to the subject on the television monitor for a preset period of time (16 seconds). Figure 2 shows the basic equipment block diagram.

The stimuli consisted of two 8 1/2 x 11 inch glass slides containing various width lines oriented in horizontal and vertical positions, as shown in Figure 3. The eleven lines varied in width from one inch to about .004 inches. The lines were grouped in an ascending series of widths from the smallest to the largest.

Four separate series of lines were displayed on each slide. Line length was varied from one inch to one-fourth inch, and a separate series of line

widths was constructed for each length. This resulted in each slide having a total of 44 lines - four ascending width series of eleven lines.

The horizontally and vertically oriented slides were constructed on a large clear sheet of plastic at four times the desired size and were later photographically reduced to the proper dimensions. These were then sandwiched between plates of glass and displayed in a Diamond Electronics Light Box.

## Experimental Design

The experiment consisted of measuring subjects' minimum perceptible acuity, which may be defined as the minimum visual angle necessary to see an object, or to see small objects against a plain background (Wulfeck, 1958). A subject's performance on this task was indicated by the smallest width line he could distinguish.

The experimental design was a complete factorial, testing 48 noise-bandwidth combinations on both spatial orientations. Noise was presented at the eight S/N ratios of 6, 12, 18, 24, 30, 36, 42, and 48 db. Six values of bandwidth were tested: .5, 1.0, 1.5, 2.0, 2.5, and 3.0 MHz. These particular values of noise and bandwidth were chosen to represent typical television system operating ranges. Each stimulus condition yielded four scores corresponding to each of the four line lengths. Hence, 192 responses were recorded for each subject on each of the two spatial orientations, making a total of 384 responses per subject.

## Procedure

A test run began by placing a subject in a dimly lighted experimental "chamber." This chamber was approximately five feet wide and eight feet long and was partitioned from the rest of the room by black plastic walls. The

subject sat in a chair which was positioned for a constant visual viewing distance of 28 inches from the monitor to his eyes. He was instructed not to squint or lean forward during the experiment.

Subjects were told that a "ready" signal would be given approximately one second before presentation of the test stimulus. The image would then appear for sixteen seconds. They were told that the experiment was not a speed test and more time would be given if requested (rarily did they do so). Subjects were then shown one typical visual condition and were instructed how to respond.

Subjects responded by specifying individually the smallest width line that they could see in each of the four lengths. They responded on an 11-point numerical scale corresponding to the lines shown in Figure 3. A response of 1 corresponded to the smallest line, and a response of 11 referred to the largest width line displayed. After recording the subject's responses on all 48 noise-bandwidth conditions for the horizontal orientation, the process was repeated for the vertical orientation thus completing the experiment.

Each subject received a different randomized sequence of stimuli. In addition, half of the subjects viewed the vertical slide first. By these methods the effects of practice and fatigue were cancelled.

To further control extraneous variables, the television screen was masked to only permit viewing of the four line series. Slots were cut in a gray cardboard mask for each series, and the lines were numbered on the mask to permit identification.

Data Reduction

The electronic system (i.e., TV camera and monitor) employed to translate the stimulus lines into visual television signals had a nonlinear effect

upon the line widths. Thus, the smaller line widths did not proportionately differ as much on the television monitor as they did on the initial slides. Since the criterion measured was the smallest line perceptible to the subject, an accurate measure was required for the actual line widths displayed on the monitor. Photographs were taken of the displayed images in all test conditions and were expanded to four times the screen size for more accurate measurements.

## RESULTS

A repeated measures analysis of variance was conducted on the subjects' response scores to determine the effects of noise, bandwidth, line length, and spatial orientation on minimum perceptible acuity. All four factors were found to significantly affect visual performance ($\alpha$ = .0001). All these results had been anticipated and are not pertinent to this paper, so they will not be discussed at length.

Since most television images contain many different length lines and spatial orientations, scores for the four line lengths and two orientations were averaged. Mean acuity scores were calculated across subjects for each of the 48 noise-bandwidth combinations.

These means were then used to calculate curvilinear regression equations for each noise and bandwidth value. For example, a curvilinear equation was obtained for a bandwidth of 1.5 MHz by fitting a curve to the acuity scores of the eight different corresponding S/N ratios experimentally tested. Such equations allowed accurate predictions of acuity scores for S/N ratios not tested in the experiment. Similar equations were obtained for the eight S/N ratios experimentally tested, allowing accurate prediction of acuity scores for bandwidths not experimentally tested. In this manner, a total of 14 different regression equations was obtained.

Using these regression equations, the point of optimum subjective performance was determined for various cost/bauderate curves. The degree of subjective performance was indicated by acuity scores for various points along these curves. For example, in Figure 1, the minimum perceptible line width at the S/N ratio of 44.5 db was .0275 inches. Conversely, the bandwidth of 2.5 MHz on this curve corresponded to a minimum perceptible line width of .0198 inches. These values only hold true for this specific cost curve (10 megabauds). The results of three similar analyses are shown in Figure 4.

The point of optimum subjective performance was found to be at the widest bandwidth tested on all cost/bauderate curves, with perceptual acuity increasing monotonically with bandwidth. Figure 4 shows that perceptual acuity on the 10 megabaud curve improved from .031 inches to .0188 inches when bandwidth increased from .5 to 3.0 MHz.

In addition, with bandwidth maximized, increasing bauderate (i.e., decreasing the noise holding bandwidth constant) did not increase perceptual acuity. Thus, decreasing the amount of noise present in the picture from 20 db S/N (lowest cost curve tested) to 44 db S/N (highest cost curve tested) did not significantly affect the subjects' perceptual acuity at the maximum bandwidth tested.

Acuity scores for other bandwidths did not significantly differ across bauderates. Hence, the S/N ratio had negligible affect on visual acuity over all bandwidths tested.

## DISCUSSION

The point of optimum subjective performance was found at the widest bandwidth on all cost/bauderate curves. Thus, optimum performance may be achieved simply by maximizing the frequency spectrum of the video signal. It was also found that increasing the system bauderate does not enhance subjects' perceptual acuity. Noise had little or no effect on the minimum perceptible acuity over all bandwidth ranges tested. Since the S/N ratio determines system cost and bauderate for given bandwidths, it may therefore be inferred that increases in system cost are not accompanied by improved visual performance. The simplest, most inexpensive system tested provided the same perceptual performance as more complex, costly systems.

Results shown in Figure 4 also indicate that increases in bandwidth beyond 3.0 MHz would probably not greatly affect perceptual performance. For example, increasing bandwidth from .5 to 1.0 MHz on the 10 megabaud curve improves minimum perceptible acuity .0045 inches, while increasing bandwidth from 2.5 to 3.0 MHz only changes visual acuity .001 inch. Visual acuity is greatly affected by low frequency bandwidth changes, but is progressively less influenced as bandwidth is increased. Relatively small acuity changes would be anticipated as bandwidth is increased beyond 3.0 MHz.

Bandwidth had a greater influence on perceptual performance than did the signal-to-noise ratio. Bandwidth directly affected the width of the lines, whereas noise tended to mask them. When bandwidth was maximized at 3.0 MHz, the discrete "luminous noise points" were significantly smaller than the smallest line width. The noise did not effectively mask the lines and thus did not affect performance.

It is possible that different results might have been obtained using a different criterion measure. Rather than measuring the subjects' minimum

acuity, one could have measured target detection time, target detection accuracy, motion detection, reading accuracy, or a host of other picture quality criteria. It is possible that noise might affect these more complex measures to a greater degree than it did minimum perceptible acuity because higher cognitive processes are involved in the other tasks. This question can only be answered by further, more complex studies.

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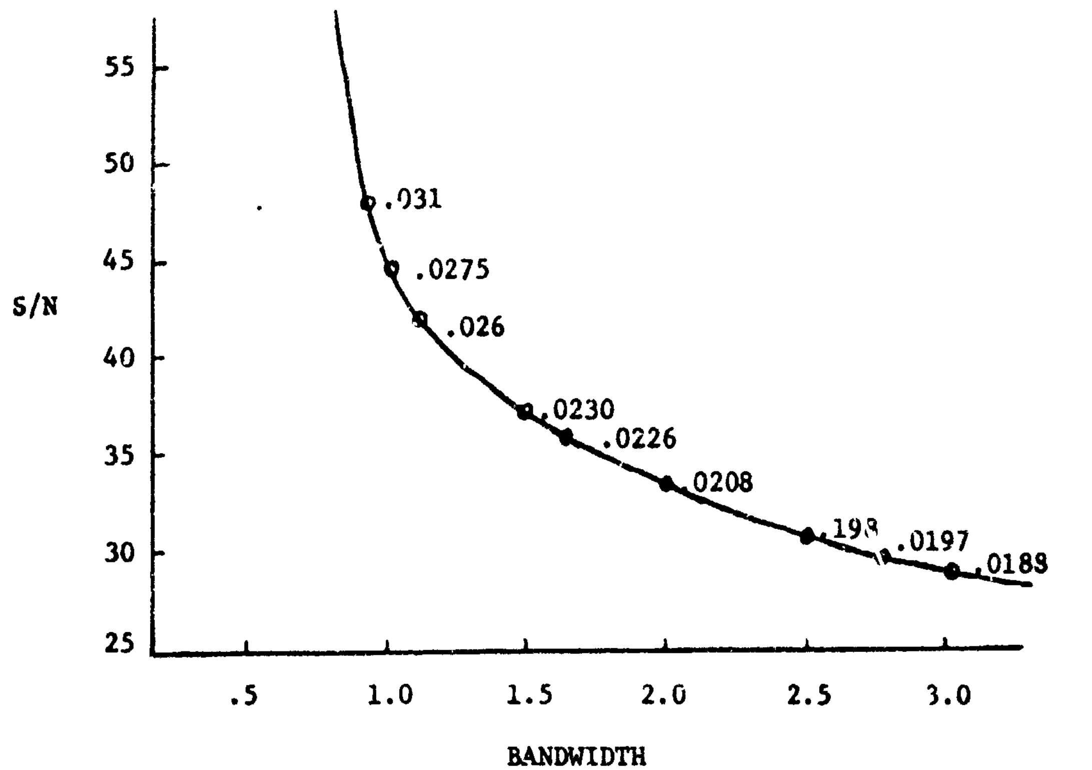


Figure 1. Constant cost/bauderate curve with minimum perceptible acuity scores indicated (in inches). Bauderate = 10 megabauds

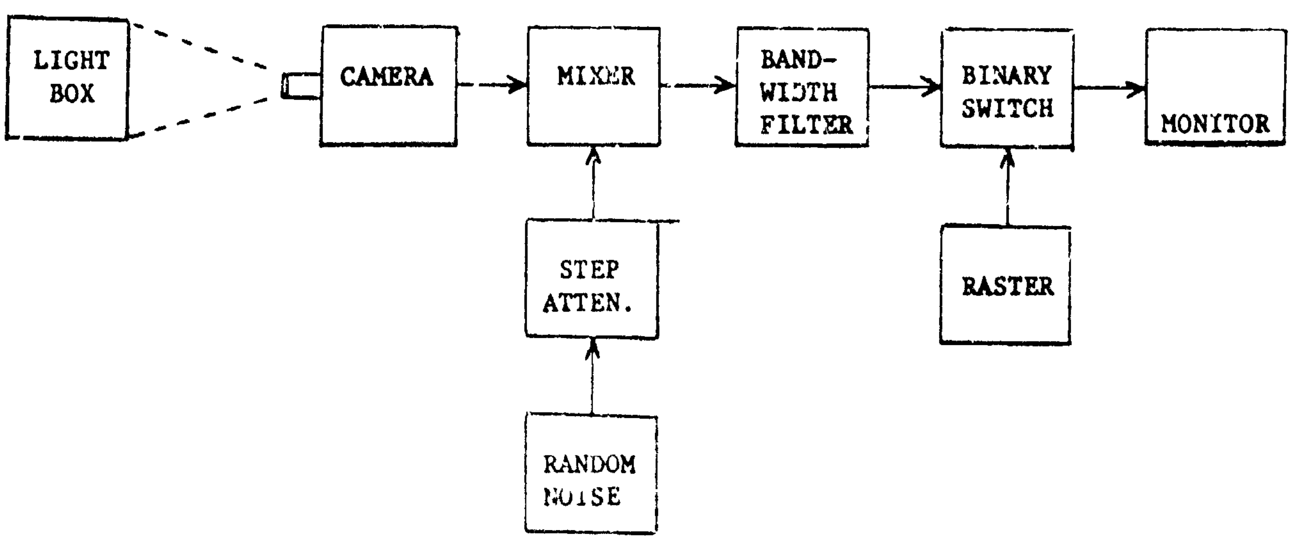


Figure 2. Block diagram of television image display system

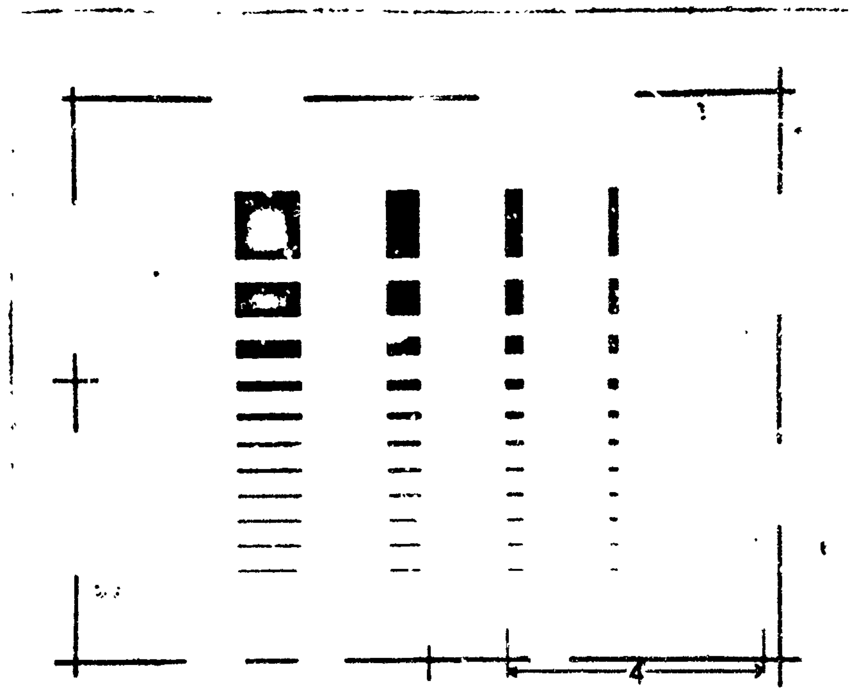


Figure 3. Stimulus slide showing lines used to measure minimum perceptible acuity. Slide was rotated 90° for vertical orientation

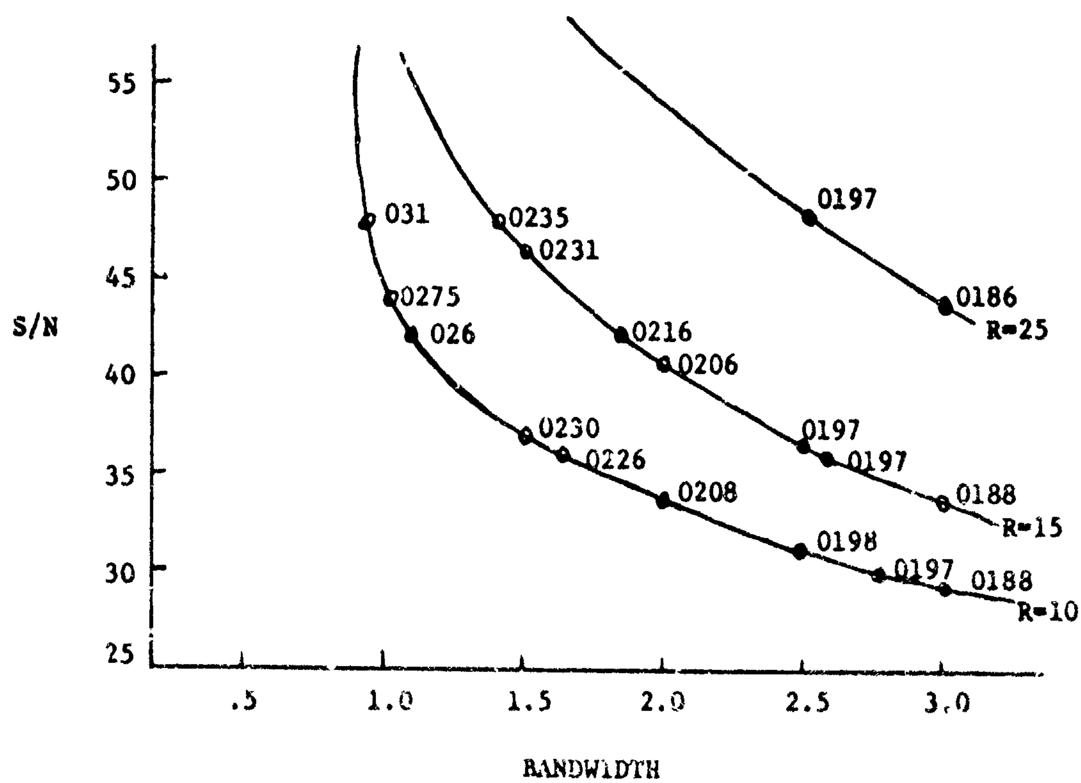


Figure 4. Minimum perceptible acuities (in inches) for three different bauderates (in megabauds)